N66 24632

25. ENDLESS-BELT TECHNIQUE FOR GROUND SIMULATION

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SUMMARY

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The use of an endless-belt ground plane for ground simulation in wind-tunnel tests has been investigated. Results of the investigation presented herein indicate that the endless-belt ground plane correctly simulates the ground but that not all models require this technique of simulation. In general, those configurations in which the lift is carried primarily in discrete jets (tilting ducted and jet V/STOL) do not require the endless belt for ground simulation and those in which the lift is distributed over the span of the wing do require the endless-belt ground plane. However, the need is dependent upon the lift coefficient and height above the ground.

INTRODUCTION

Author

Normally in wind-tunnel investigations of ground effects the ground is simulated by placing a board in the airstream immediately below the model, as illustrated in figure 1. This simulation is not strictly correct because a boundary layer develops between the airstream and the ground board. This boundary layer has not been a serious problem in tests of conventional aircraft models. However, with the advent of V/STOL configurations in which a jet sheet or propeller slipstream is used to augment the lift, the question of possible interaction between the jet sheet or slipstream and this boundary layer arises. If an endless belt moving at the same velocity as the tunnel airstream instead of the conventional fixed ground board is used for ground simulation, the boundary layer can be eliminated. The present investigation was therefore made to study this method of ground simulation and to determine the conditions under which it would be preferable to the conventional method.

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SYMBOLS

A	aspect ratio
b	span, feet
C_D	drag coefficient, $\frac{\text{Drag}}{q_\infty S}$
C_L	lift coefficient, $\frac{\text{Lift}}{q_\infty S}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty S\bar{c}}$

C_T thrust coefficient, $\frac{\text{Thrust}}{q_\infty S}$

$\bar{c}$ mean aerodynamic chord, feet

h height of wing chord above ground, feet

L_h lift at height h above ground, pounds

$L_{h=\infty}$ lift out of ground influence, pounds

$\Delta L_h = L_h - L_{h=\infty}$

q_∞ free-stream dynamic pressure, pounds/foot^2

S area, feet^2

V velocity, feet/second

α angle of attack, degrees

δ_{duct} duct deflection from horizontal, degrees

∞ free stream or infinity

BASIC CONSIDERATIONS

In order to investigate whether or not the boundary layer caused by the conventional ground board produced possible adverse effects, experiments were made a few years ago by using a carriage to move a model through still air over the ground in the same fashion as an airplane landing or taking off (ref. 1). This same model was then tested over a conventional fixed ground board in a wind tunnel. The lift results from these investigations are compared in figure 2. The increment of lift loss in ground effect divided by the lift out of ground effect is presented as a function of model height in spans. The full-span blowing-flap configuration of aspect ratio 6 developed a lift coefficient out of ground effect of 9.5. The lift loss over the fixed ground board was much greater than that experienced with the moving-model technique. The increment between the curve for the moving model and zero represents the true loss in lift that this type of configuration would experience in ground effect. The increment between the two curves is the additional lift loss caused by the boundary layer on the conventional fixed ground board.

Figure 3 shows schematically the type of flow that has been observed in tests over the endless-belt ground plane, to be described later, and in

O.N.E.R.A. water-tunnel flow visualization experiments (ref. 2). The top sketch shows the flow pattern around the model with the ground plane moving at stream velocity V with no boundary-layer loss, as illustrated on the left. The jet sheet from the model impinges on the ground board with some of the sheet attempting to flow forward under the model. This forward flow can penetrate the high-energy free-stream air only a short distance. The bottom sketch shows the flow field around the model over a fixed ground board with the velocity profile at the left showing the loss in energy in the boundary layer on the ground board. The jet sheet impinges as before but the part of the sheet that flows forward under the model can penetrate farther because of the low energy of the stream air near the board; this upstream penetration thus separates the boundary layer even upstream of the model. This boundary-layer separation results in an appreciable alteration of the flow field in the vicinity of the model, as indicated by the relocation of the stagnation streamline.

The flow visualization tests and the preceding test data indicate that, for this type of configuration, it is necessary to eliminate the boundary layer on the ground board for proper ground simulation. The moving-model technique was not used further because of the inherent problems associated with the technique and because the technique does not have the flexibility and adaptability normally associated with wind-tunnel testing. It was, therefore, decided to develop the endless-belt ground plane shown schematically in figure 4 for the 17-foot test section of the Langley 300-MPH 7- by 10-foot tunnel (ref. 3). A similar installation had been developed earlier by the R.A.E. in England (ref. 4).

ENDLESS-BELT GROUND PLANE

The endless belt used to simulate the ground plane in this testing technique is 10 feet long and 12 feet wide, and the belt upper surface is 10 inches above the tunnel floor. (See fig. 4.) A 1-inch suction slot extends the width of the belt at the leading edge to remove any boundary layer up to this point, and with the belt moving at stream velocity no boundary layer can build up downstream. The belt is made of 1/8-inch-thick plastic-impregenated woven wool and can be driven at velocities from 0 to 100 feet per second. The model is mounted on an internal strain-gage balance fitted to a sting that can be remotely driven to change model height and attitude. The photograph in figure 5 shows the endless-belt ground plane installed in the test section. The full-width boundary-layer-removal slot and the belt upper surface can be observed.

RESULTS AND DISCUSSION

Distributed-Lift Configurations

The first model investigated over the Langley endless-belt ground plane was the same model used in reference 1 to obtain the moving-model data presented in figure 2. Figure 6 presents the data of figure 2 along with data from the endless-belt technique. The ratio of lift loss in ground influence to lift out of ground influence is plotted as a function of wing height in spans. With the belt velocity equal to air velocity the lift loss is in good agreement with the moving-model data. With the belt velocity equal to zero the lift loss is in good agreement with the conventional ground board results.

In theory the velocity of the belt must be the same as the airstream velocity. The data presented in figure 7 show the effect of varying the belt velocity from values less than to values greater than stream velocity. These results are for an out-of-ground-influence lift coefficient of 7.4. The lift loss is plotted as a function of the ratio of belt velocity to air velocity. The insets show the type of boundary layer existing over the belt at velocity ratios of 0, 1.0, and 1.4. The lift loss for the given conditions decreases almost linearly with increasing velocity ratio. The slope of the lift-loss curve is such that extreme precision is not required in setting belt speed. Normally the moving belt would be used to simulate take-off and landing in still air, that is, belt velocity equal to free-stream air velocity. However, with the belt operating below stream velocity, head wind conditions may be approximated if the boundary-layer profile on the runway is known.

All the ground influence effects presented up to this point have been based on blowing-flap configurations developing very high lift coefficients. However, various other models typical of existing or proposed aircraft configurations including delta-wing, double slotted flap, tilting ducted fan, propeller powered tilt-wing, and other configurations have been investigated over the endless-belt ground plane. The main factors influencing the ground flow conditions which determine the need for the endless-belt ground plane appear to be lift (including spanwise distribution) and height above the ground. In general, configurations which operate at high circulation lift coefficients, such as tilt-wing, jet-flap, and in some cases unpowered double slotted flap configurations, require the belt.

Other models, even without blowing flaps, show a need for the belt if the height of the model above the belt is low enough. Some ground influence results for a double slotted flap configuration very near the ground ($h/b = 0.033$) are presented in figure 8. There is a large loss in lift due to ground effect at $\alpha = 0$ with the belt stopped, but essentially zero loss with the belt running at stream velocity. The changes in drag and pitching moment are a reflection of the lift changes.

Ground effect data for a tilt-wing propeller-powered configuration (XC-142A) are presented in figure 9. The wing is tilted 20° and the flap is deflected 60°. This configuration develops lift coefficients from 6.0 to 8.0. A significant loss in lift occurs as the height decreases from infinity to 0.19 spans with the belt stopped, but with the belt running this loss is reduced. There is a large effect of the ground on the pitching-moment coefficients, due primarily to the change in downwash caused by the ground, but a negligible effect on the endless belt for this moderately high tail configuration.

A correlation in terms of lift coefficient and ground height for full-span high-lift configurations, which shows conditions that require the moving belt, is shown in figure 10. The plotted points are the lift values for a given height at which the lift curves for belt velocity equal to air velocity and belt velocity equal to zero noticeably diverge, as illustrated in the inset. The solid line in figure 10 is the height above the ground computed for a given lift coefficient by assuming that the effective deflection angle θ_{eff} for the stream tube impinges on the ground a distance of 2.5 spans downstream from the model. It should be noted that θ_{eff} is equal to one-half the deflection calculated from momentum theory, as explained in paper no. 24 by Heyson and Grunwald. (The stream-tube deflection angle of the present paper is the complement of the wake skew angle used in paper no. 24.) The agreement between the plotted points and the solid (boundary) line is interesting. It is also interesting to note that the downstream distance of 2.5 spans is almost the same as the impingement distance at which recirculation effects in the wind tunnel begin to produce noticeable effects on the data (paper no. 24). However, elimination of the boundary layer on the ground by means of the endless-belt technique may alleviate the circulation effects to some degree. The conventional ground board is adequate for those combinations of lift and height falling above the boundary shown by the solid line. For those combinations falling below the boundary shown, the moving belt is required.

Direct-Lift Configurations

In general, configurations in which the lift is concentrated in discrete jets, such as direct-jet VTOL and tilting ducted models, do not require the belt, as is illustrated in figure 11. Although there is clearly an effect of the ground on all components, there is no measurable effect of the moving belt.

CONCLUDING REMARKS

Results of an investigation of an endless-belt ground plane for ground simulation indicate that the endless-belt ground plane correctly simulates the ground but that not all models require this technique of simulation. In general, those configurations in which the lift is carried primarily in discrete jets (tilting ducted and jet V/STOL) do not require the endless belt for ground simulation and those in which the lift is distributed over the span of the wing do require the endless-belt ground plane. However, the need is dependent upon the lift coefficient and height above the ground.

REFERENCES

1. Turner, Thomas R.: Ground Influence on a Model Airfoil With a Jet-Augmented Flap as Determined by Two Techniques. NASA TN D-658, 1961.

2. Werlé, Henri: Simulation de L'Effet de Sol au Tunnel Hydrodynamique (Ground-Effect Simulation at the Water-Tunnel). La Rech. Aérospatiale, no. 95, July-Aug. 1963, pp. 7-15.

3. Vogler, Raymond D.: Ground Effects on Single- and Multiple-Jet VTOL Models at Transition Speeds Over Stationary and Moving Ground Planes. NASA TN D-3213, 1966.

4. Williams, John; and Butler, Sidney F. J.: Further Developments in Low-Speed Wind-Tunnel Techniques for VSTOL and High-Lift Model Testing. AIAA Aerodynamic Testing Conf., Mar. 1964, pp. 17-32.

CONVENTIONAL WIND-TUNNEL GROUND BOARD

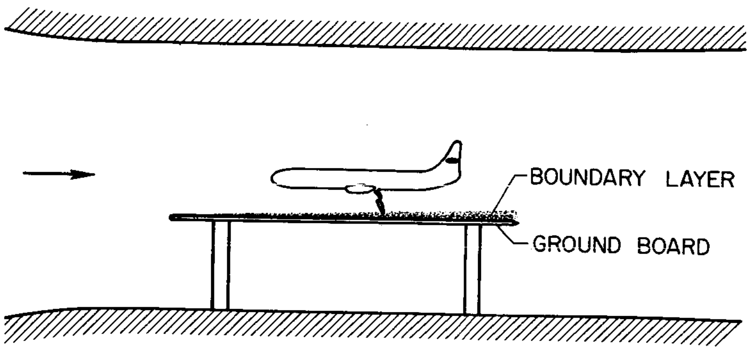

Figure 1

LIFT LOSS FOR MOVING MODEL AND CONVENTIONAL GROUND BOARD

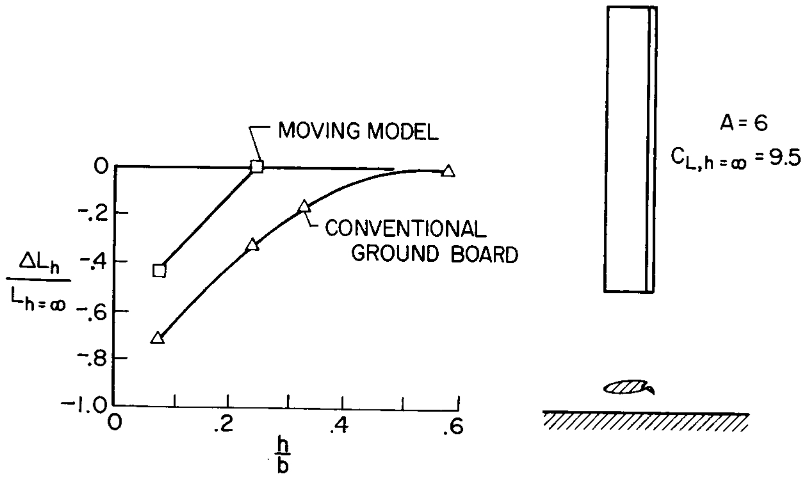

Figure 2

FLOW STUDIES OVER FIXED AND MOVING GROUND PLANES

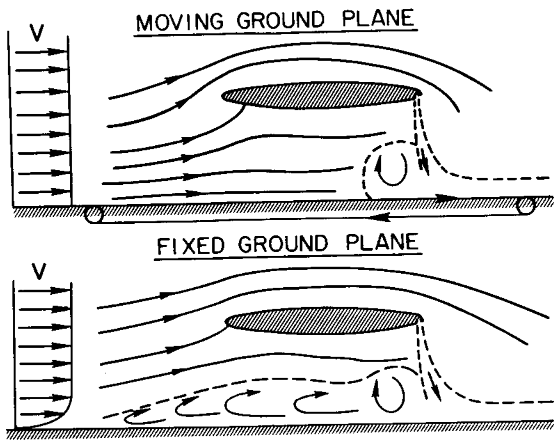

Figure 3

ENDLESS-BELT GROUND PLANE IN
17-FOOT TEST SECTION

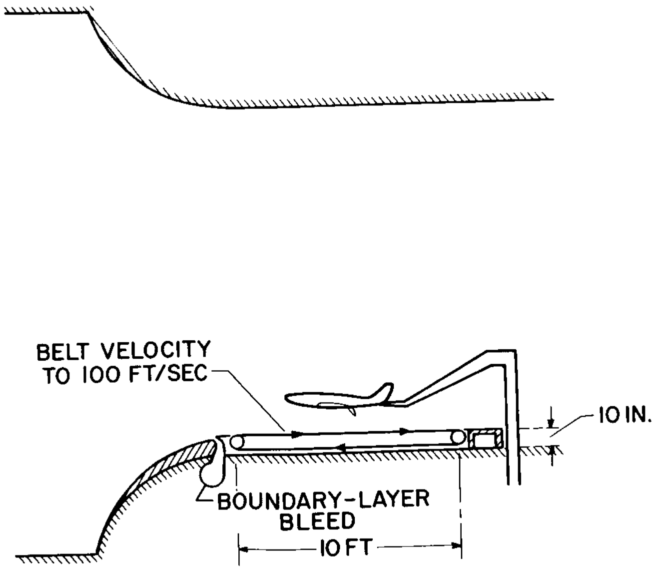

Figure 4

PHOTOGRAPH OF ENDLESS-BELT GROUND PLANE

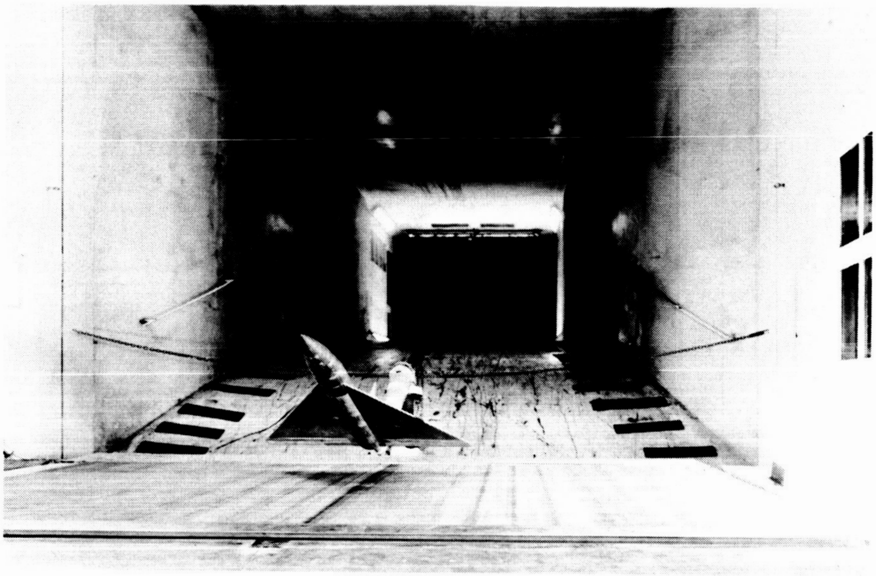

Figure 5

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LIFT LOSS FOR MOVING MODEL AND ENDLESS-BELT GROUND PLANE

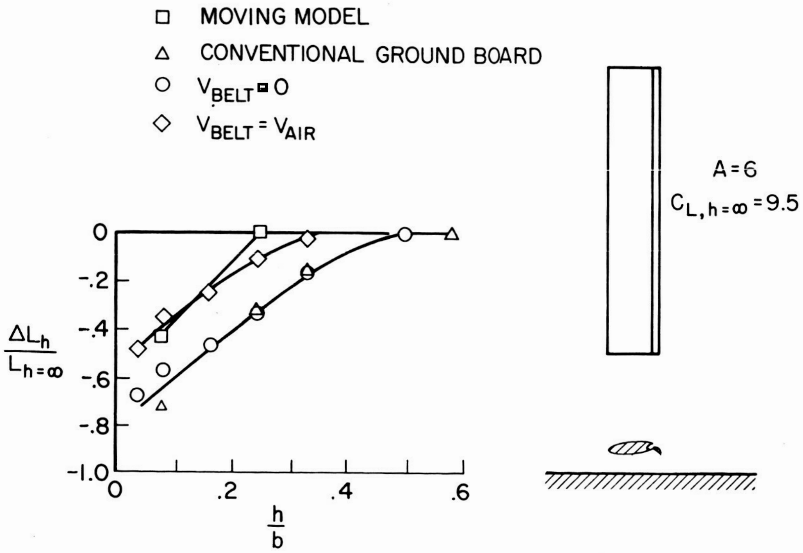

Figure 6

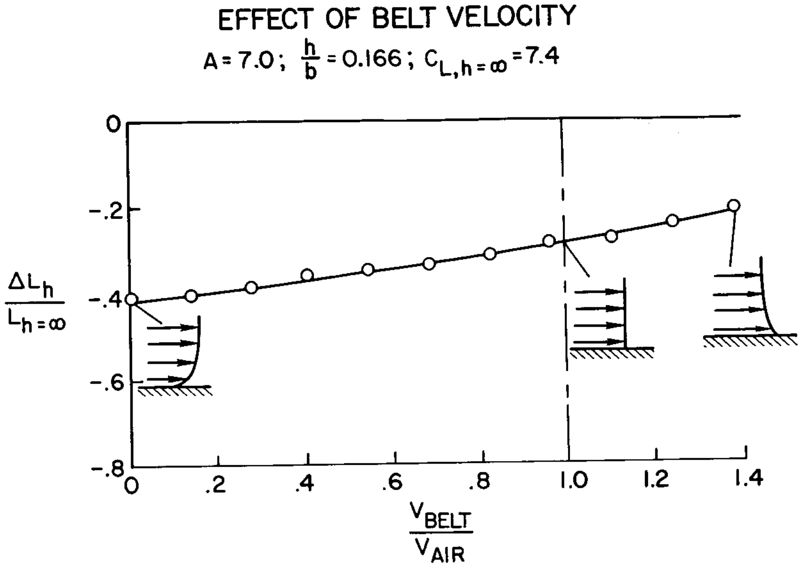

Figure 7

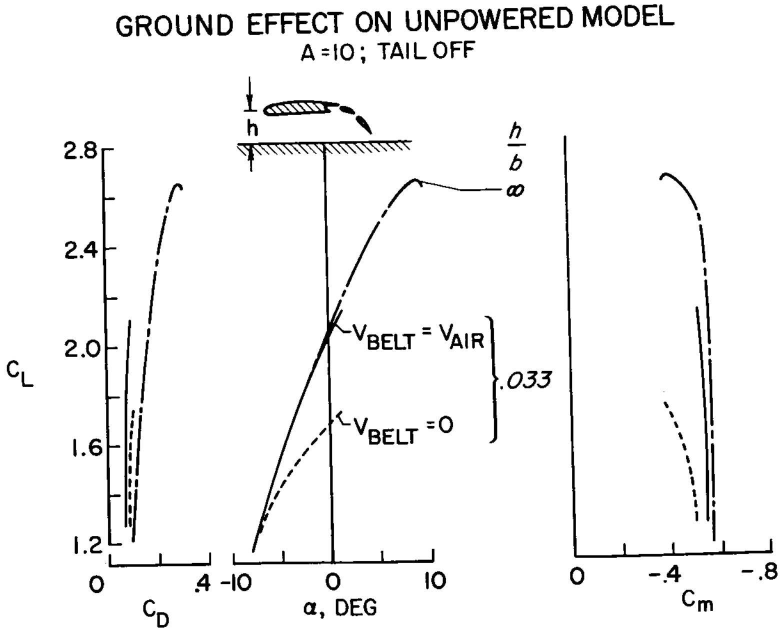

Figure 8

GROUND EFFECT ON TILT-WING CONFIGURATION

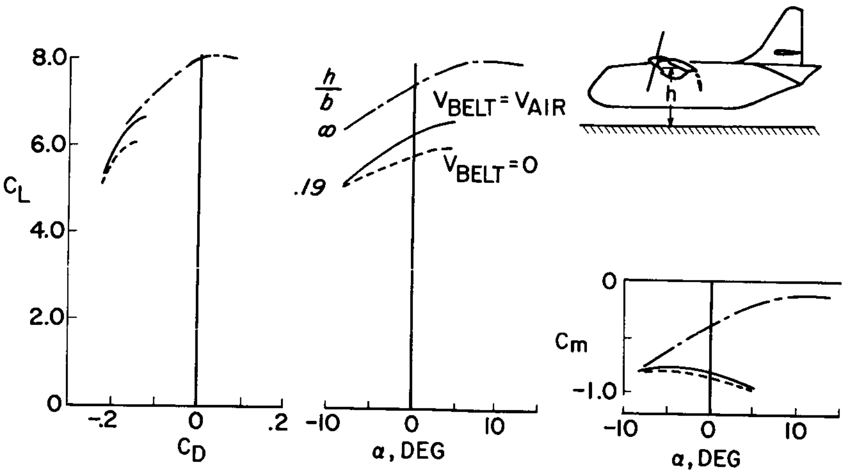

Figure 9

CONDITIONS REQUIRING ENDLESS-BELT GROUND PLANE

FULL-SPAN HIGH-LIFT CONFIGURATIONS

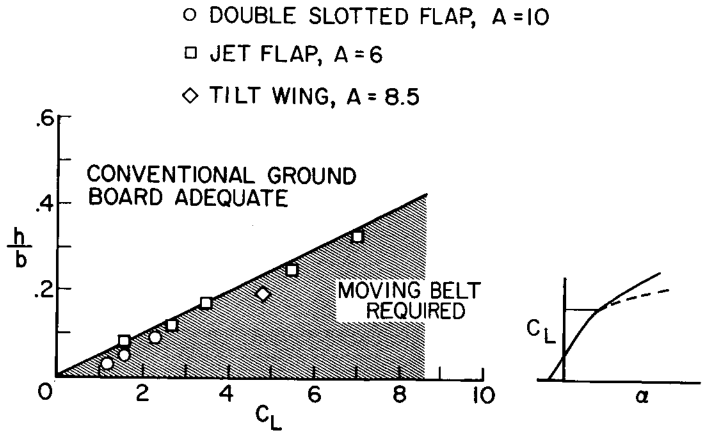

Figure 10

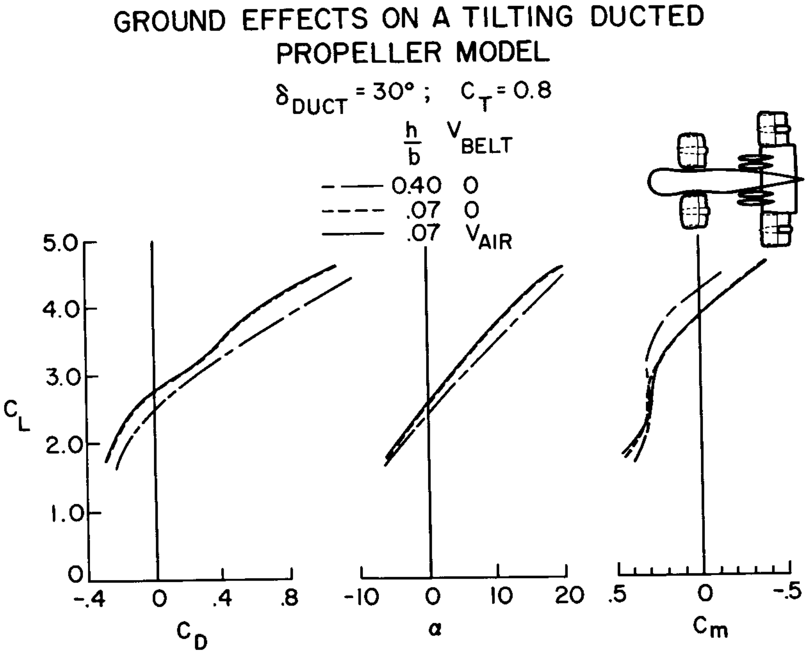
GROUND EFFECTS ON A TILTING DUCTED PROPELLER MODEL
$\delta_{DUCT} = 30°$; $C_T = 0.8$
$\frac{h}{b}$ V_{BELT}
0.40 0
.07 0
.07 V_{AIR}
C_L
5.0
4.0
3.0
2.0
1.0
0
-.4
0
.4
.8
C_D
-10
0
10
20
α
.5
0
-.5
C_m

Figure 11